# CHAPTER 10

# NONDESTRUCTIVE EVALUATION TECHNIQUES

**10-1. Introduction**. This chapter provides nondestructive evaluation (NDE) techniques for masonry in existing buildings. Techniques for both the evaluation of the condition of the materials and the determination of material properties are included.

**10-2. Background.** Traditional evaluation methods for the condition and properties of masonry features of buildings have been, in addition to visual inspection, destructive testing of specimens removed from the structure. Destructive methods of evaluation are inherently limited because specimen removal may be aesthetically and structurally damaging. Further, because of the potentially structurally destructive nature of these methods and the facts that they can be relatively expensive and aesthetically unpleasant, the number of specimens taken may be limited to a small number. Thus, potentially, the quantity and quality of the resulting data may be poor and/or inconsistent.

**10-3. NDE methods**. The use of NDE techniques can provide the structural engineer, who is charged with evaluating the structural integrity and serviceability of the masonry features of an existing structure, invaluable information. NDE methods can be used in conjunction either with each other or with destructive methods. The NDE methods described herein are those which offer the greatest potential at the present time for determining the location of flaws within masonry members and for assessing masonry materials properties.

**10-4. Application of Combined Techniques.** Combined NDE techniques. It is apparent that, of the methods described here, no single technique will be sufficient for “complete” nondestructive evaluation of masonry, where the term “complete” means comprehensive evaluation of both condition and quality. The mechanical tests, such as the flatjack, and in-place shear test, provide data directly related to quality, and perhaps indirectly a measure of condition. Conversely, impact and stress wave techniques evaluate condition and indirectly measure quality. Furthermore, the results from the latter techniques are often difficult to interpret in the absence of information about the state of stress that can be provided by the flatjack test. At the present time, therefore, the scenario for utilization of NDE techniques calls for use of two or more complimentary techniques for most evaluation studies. Each technique must be used to its best advantage in combination with others to develop a body of evidence upon which conclusions and decisions may be made regarding existing conditions and rehabilitation measures required for masonry structures. Table 10-1 lists each NDE technique along the top and gives the desired information along the left side, which are grouped under the headings of material properties and condition. A simple matrix of dots indicates which techniques are useful for measuring each of the desired quantities. A filled dot indicates the technique is useful while an unfilled dot indicates that the technique is useful, but may be affected by conditions such as loading and crack distributions in the walls. Thus, the techniques with unfilled dots should be used in tandem with others to strengthen the reliability of the results.

**10-5. NDE Tests.**

*a. Schmidt Hammer.* The Schmidt Hammer test is the quickest, simplest, and least expensive method for NDE of solid clay unit, i.e., brick masonry. As shown in figure 10-1, studies show a reasonably good correlation between the rebound number and the compressive strength of clay brick masonry.

The Schmidt Hammer is most ideally suited to the measurement of material uniformity over large areas of a structure. It must be accompanied by a limited number of destructive tests to calibrate the results if an indication of the actual masonry strength is required. The simplicity of the test is offset by its limited utility. Its use is suggested only for determination of the uniformity of properties over a large area of a structure.

(1) *Equipment.* The Schmidt Hammer is a compact, lightweight instrument that provides a measure of relative material surface hardness. It has been used extensively in the testing of concrete and rock. The hammer consists of a spring loaded plunger which, when released, strikes a surface and causes a mass within the hammer to rebound. The magnitude of the rebound is indicated on a scale at the “rebound number”. This number gives an indication of surface hardness which can be correlated to the strength or condition of the material. For the evaluation of solid clay (brick) masonry units, the hammer is pressed against the center of the vertical surface of an individual brick in a wall. The rebound number is a function of the brick hardness and the mortar in which the brick is

| | Required Information for Structural Evaluation / Nondestructive Testing Techniques | Schmidt Hammer | Single Flatjack | Double Flatjack | In-Plane Shear | Modified Shear Test | Ultrasonic Pulse | Mechanical Pulse | Magnetic Method | Visual |
|---|---|---|---|---|---|---|---|---|---|---|
| MATERIAL PROPERTIES | Compressive Strength (Direct) | | | ● | | | | | | |
| | Compressive Strength (Indirect) | ● | | | | | ○ | ○ | | |
| | Deformability | | | ● | | | | | | |
| | Joint Shear Strength | | | | ○ | ● | | | | |
| | Coulomb Shear Relationship | | | | | ● | | | | |
| CONDITION | Voids Between Wythes | | | | | | ● | ● | | |
| | Cracks in Outer Wythes | | | | | | ○ | ○ | | ○ |
| | In-Situ Stress | | ● | | | | | | | |
| | Material Uniformity | ● | | | | | ● | ● | | ○ |
| | Location of Reinforcement | | | | | | | | ● | |

● Useful for evaluation

○ Useful, but may require additional information regarding loading conditions and crack distributions

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*Table 10–1. Use of NDE methods.*

embedded. Test hammers are available in four basic varieties; Type L, .Type N, Type M, and Type P; which are distinguished primarily by their impact energy. The type N hammer has a tendency to crush the brick unit material under the tip, particularly for older, lightly burned units. For this reason, a type L hammer with lower impact energy is recommended to prevent damage to the masonry units.

(2) *Use.* The application of the Schmidt Hammer to concrete testing is governed by ASTM C 805. There is no standard at this time for the use of the Schmidt Hammer on masonry materials. An experimental procedure has been adopted for testing masonry structures which is based upon the International Society for Rock Mechanics (ISRM) suggested method for determining Schmidt rebound hardness. While laboratory tests have shown that a relationships may exist between rebound number and masonry compressive strength under controlled conditions, the general applicability of such a relationship has not been verified. Therefore, due to the wide variations in predicted strength, it is not recommended that the Schmidt Hammer be used for direct prediction of compressive strength, but only for evaluation of material uniformity. The correlation to masonry compressive strength is useful primarily for determining the expected relative change in compressive strength between locations with different rebound numbers.

*b. Flatjack methods.* The flatjack test is being recognized as a powerful tool for NDE of the structural properties of masonry. ASTM standards are currently being established for the application of flatjack testing to the evaluation of unreinforced solid clay unit (brick) masonry. The test has been successfully applied to cut stone masonry. Under the proper conditions, flatjacks can provide information on the in-situ state of stress at virtually any point in a masonry structure. The test provides a measure of the deformability of the masonry materials and in some cases, a direct measure of masonry compressive strength. No other NDE test method offers direct physical measurement of material and structural properties without any reliance on empirical correlations. The two main types of flatjack tests; the in-situ stress or single-flat jack test and the in-situ deformability or two-flatjack test; are described in the following paragraphs:

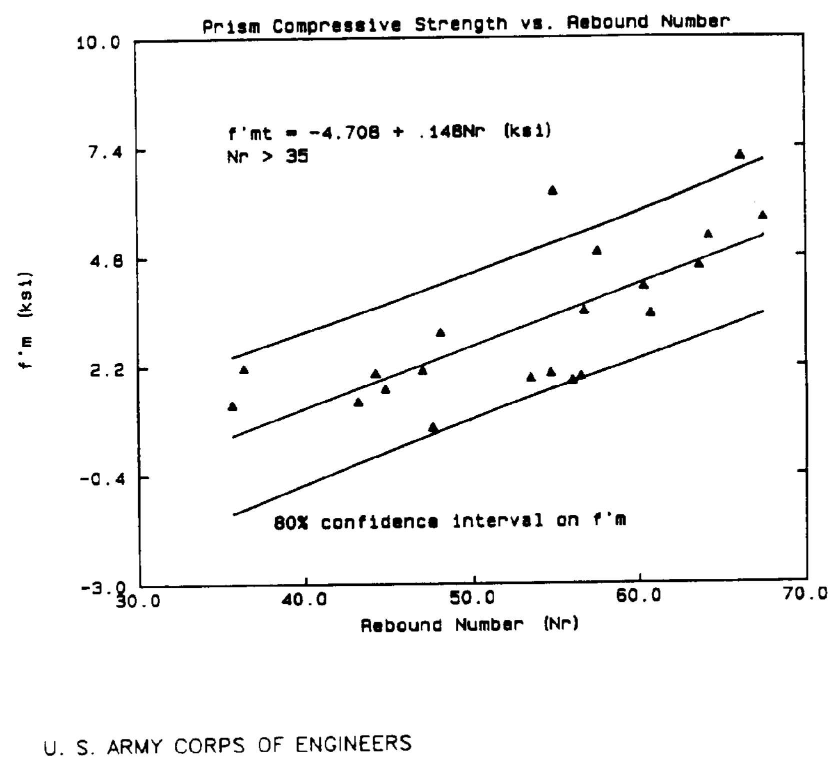


*Figure 10–1. Prism compressive strength vs. rebound number.*

(1) *In-situ stress test.* Evaluation of the in-situ compressive stress is a simple process of stress relief induced by the removal of a portion of a mortar bed joint followed by restoration of the original state of stress by pressurizing a flatjack inserted in the slot created by the removal of the mortar. When the mortar is removed from a horizontal joint, the release of the stress across the joint causes the slot to close by a small amount. The magnitude of this deformation is measured using a removable dial gauge between two or more points located symmetrically on either side of the slot. A flatjack is then inserted in the slot and pressurized until the original position of the measuring points is restored. At this point the pressure in the flatjack, modified by two constants to account for the flatjack stiffness and the area of the slot, is assumed equivalent to the original vertical compressive stress in the masonry. The technique is useful for verifying analytical models or for determining stress distributions in masonry walls when conditions of loading or displacement are unknown or difficult to quantify. Typical test results, as shown in figure 10-2, are a plot of masonry deformations around a slot for various levels of internal flatjack pressure. Past results show that the in-situ stress test is able to estimate the actual state of masonry compressive stress to within 10% to 15%.

(2) *In-situ deformability test.* The deformation properties of masonry may be evaluated by inserting two parallel flatjacks, one directly above the other separated by several courses of masonry, and pressurizing them equally, thus imposing a compressive load on the intervening masonry. The deformations of the masonry between the flatjacks are then measured for several increments of load. The results are used to calculate the masonry deformability modulus. If some damage to the masonry is acceptable, the masonry may be loaded to failure to determine the maximum strength. This technique is useful when an estimate of material deformability or strength is needed for stress analysis or deflection calculations. Test results in the form of a cyclic stress-strain curve along with the test setup are shown in figure 10-3. This in-situ deformability test provides a reasonably accurate measure of masonry compressive modulus, typically overestimating the masonry stiffness by approximately 10%.

(3) *Equipment.* A flatjack is a thin steel bladder that is pressurized with oil to apply a uniform stress over the plan area of the flatjack. In masonry structures, flatjacks are inserted in slots cut in mortar bed joints. Flatjacks may be made in many shapes and sizes. Flatjacks with curved edges are designed to fit in a slot cut by a circular masonry saw and rectangular jacks are used where

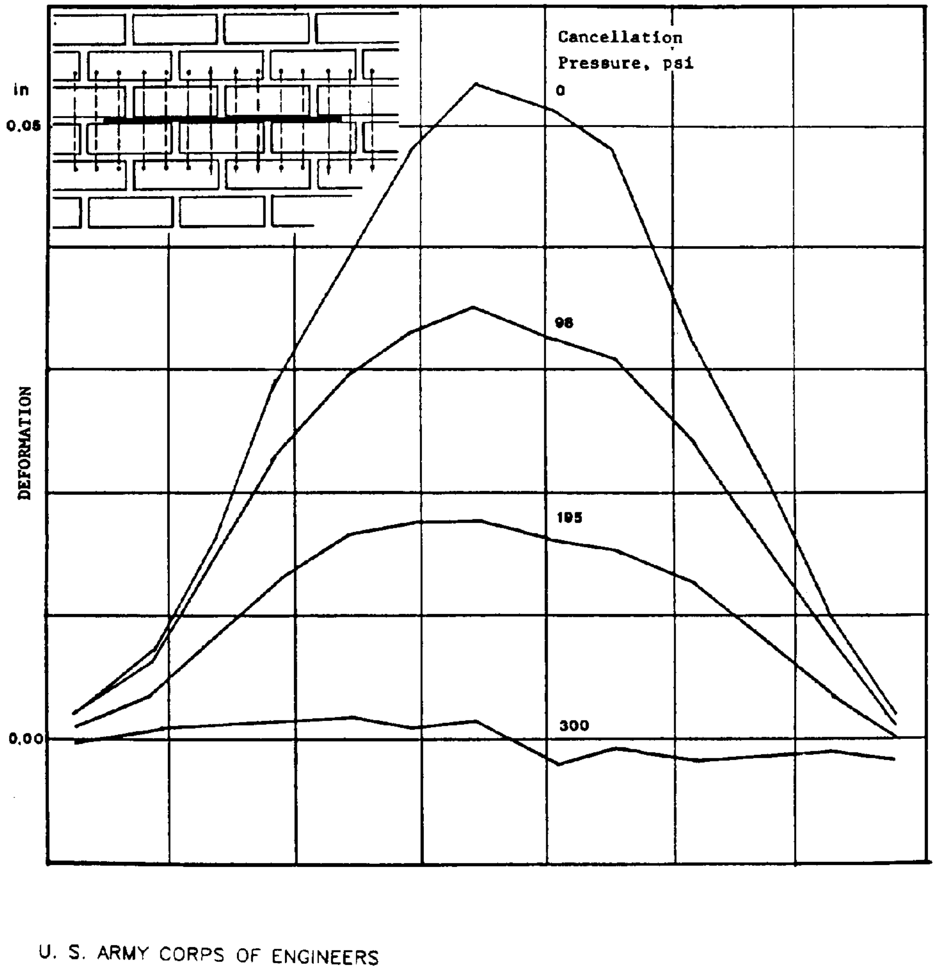


*Figure 10–2. Masonry deformations around flatjack slot during in-situ stress test.*

mortar must be removed by hand or with a drill. Semicircular jacks are suitable for in-situ stress measurement but are not suitable for deformation measurements in the two-flatjack test. Instead, rectangular or semi-rectangular flatjacks with a length equal to or greater than that of two masonry units should be used. An accurate, removable dial gauge is needed for measurement of displacements or, in the case of the two-flatjack test, electronic deformation measuring devices may be used. Other equipment required for the flatjack test includes a diamond-bladed masonry saw or a hand drill to form the slot at the chosen location, a hydraulic pump, flexible high pressure hoses, and a calibrated pressure gauge.

(4) *Application.* Flatjack tests are among the most useful and informative NDE tests available for determining masonry structural properties. Unlike other NDE tests, the flatjack test provides a direct physical measurement of the engineering material characteristics needed for structural analysis and evaluation. It does not rely upon correlation to laboratory tests. The in-situ stress test provides a direct measure of the vertical stress at a point in a structure-thus gives an indication of the factor of safety of the structure in terms of compressive failure. The measurement of in-situ stress also provides a gauge of the accuracy of structural analyses in predicting the effects of gravity loads. The in-situ deformability test yields a direct measure of the compression modulus which can be used for calculation of deflections, or for use during structural analysis. It may also be possible, in certain cases, to estimate masonry compressive strength from an in-situ deformability test. The flatjack tests are not strictly NDE tests, since they do require the removal of a portion of a mortar joint. However, this damage is easily repaired by simply repointing mortar into the slot, leaving no visible trace of the test. The flatjack test

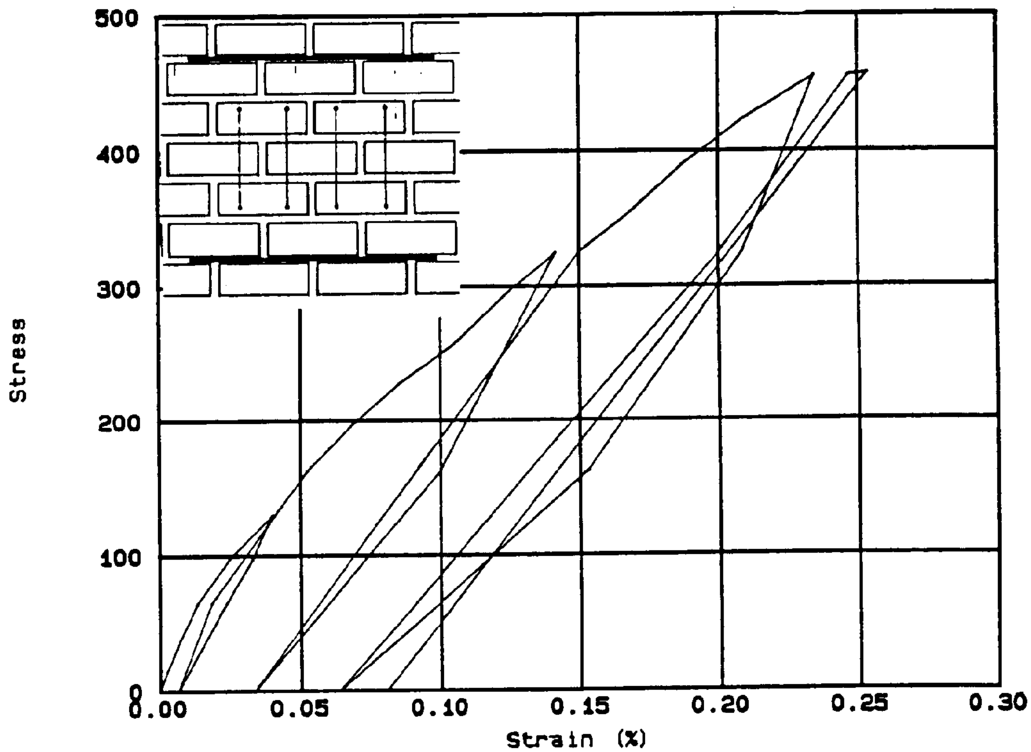


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*Figure 10–3. Stress-strain curve obtained during in-situ deformability test.*

may be easily integrated into the structural evaluation process and provide data that is complimentary to other NDE tests. Data concerning the states of stress at various points throughout the structure may be very helpful in the interpretation of data from the in-place shear test and both ultrasonic and mechanical pulse tests. Data on the elastic modulus and strength of masonry obtained from the two-flatjack test may be used for correlation to Schmidt Hammer or pulse velocity tests.

*c. In-situ shear test.* The in-place shear test, often called the push test, is designed to measure the in-situ joint shear resistance between masonry units and mortar joints. It requires the removal of a single masonry unit and a head joint on opposite sides of a test unit. The test unit is then displaced horizontally relative to the surrounding masonry using a hydraulic jack and the horizontal force required to cause the first movement of the test unit is recorded. The test may be considered nondestructive, because the removed unit and mortar joints may be replaced to their former appearance.

(1) *Existing test.* The test procedure, as described in the model codes, is not very specific about the details of the test and about the analysis of the test data. A more complete description of the test is contained in the ABK Methodology for Mitigation of Seismic Hazards in Existing Unreinforced Masonry Buildings. This shear test is the best currently available for measuring in-situ bed joint shear strength in existing masonry walls, however, several unknowns still must be accounted for by assumptions. The assumptions include, the definition of joint failure, the effect of normal load on the measured shear stress, the magnitude of the normal load on the tested joint, the contribution of the collar joint, the variability of the masonry due to workmanship in the original construction, and the correlation of the results to full-scale wall behavior. Each of these assumptions may introduce an element of inaccuracy into the determination of the available shear resistance of an existing masonry wall. These inaccuracies need to be considered if a more reliable method of determining the shear strength is to be obtained.

(2) *Modified test.* A modified technique for conducting the in-place shear test has been developed which addresses many of these assumptions and appears to give reliable results. In the modified test, the vertical stress in the wall at the test unit is measured directly using the single flatjack test. The normal stress is then controlled during the shear test by flatjacks above and below the test unit. The

test is then conducted on the same joint for several levels of normal stress, so the friction angle is measured directly rather than assumed. Electronic deformation measuring devices are used to monitor the movement of the unit continuously during the test, thus eliminating ambiguity concerning the definition of failure. The influence of the collar joint may be estimated based on a collar joint shear test. Only the effect of workmanship remains a potential source of error. The test setup for the modified in-place shear test is shown in figure 10-4. Results from this test show the relationship between increasing normal load and the resulting increasing deflection.

(3) *Application.* Because the in-place shear test measures the bed joint shear strength directly with a minimum of damage to the structure, it is an essential part of any building evaluation where lateral loads influence the building design. In some seismic regions, the existing test is required for some retrofit designs. The modified test should be conducted as an extension of a normal series of flatjack tests. The single-flatjack test reveals the in-situ state of normal stress at the test joint, and thus provides essential data for determining the expected joint shear strength in the area of the test. The two-flatjack test provides half of the required test setup for the modified in-place shear test. At the completion of the test, the engineer should know the relationship between the expected joint shear strength and the normal stress along with the measured normal stress at the test location. If similarity of materials throughout the structure can be established using a technique such as the Schmidt Hammer test, the number of required in-place shear tests can be reduced from the number determined by arbitrary methods, such as a certain number of tests per square foot, etc. It remains only to conduct the simpler single flatjack test to determine the variation of normal stresses throughout the structure.

*d. Ultrasonic Pulse.* The ultrasonic pulse velocity (UV) technique uses electroacoustic transducers to pass a high frequency (50,000 Hz) stress wave through masonry. This technique has good potential for evaluation of masonry structures and is most useful for the location of relatively small flaws in otherwise uniform masonry materials. In certain cases, it may be possible to obtain an estimate of masonry compressive strength from ultrasonic pulse velocity measurements. However, very careful interpretation of the signal is required along with a meticulous visual survey in order to interpret the data properly. It is recommended that pulse velocity techniques be used in conjunction with other NDE tests such as the flatjack test for determining the state of stress and deformability in walls and also with destructive tests to verify the deformability and strength.

(1) *Background.* The ultrasonic pulse velocity technique has only recently been applied to masonry. The studies to date have been mostly exploratory, evaluating the feasibility of using the method on masonry structures. The technique has been used effectively for concrete using ASTM C 597 for quite some time, hence the literature on testing concrete using ultrasonic pulse velocity techniques is extensive. The method has proven to be reasonably accurate for predicting concrete compressive strength using empirical relationships that were derived under carefully controlled laboratory conditions. However, a multitude of factors

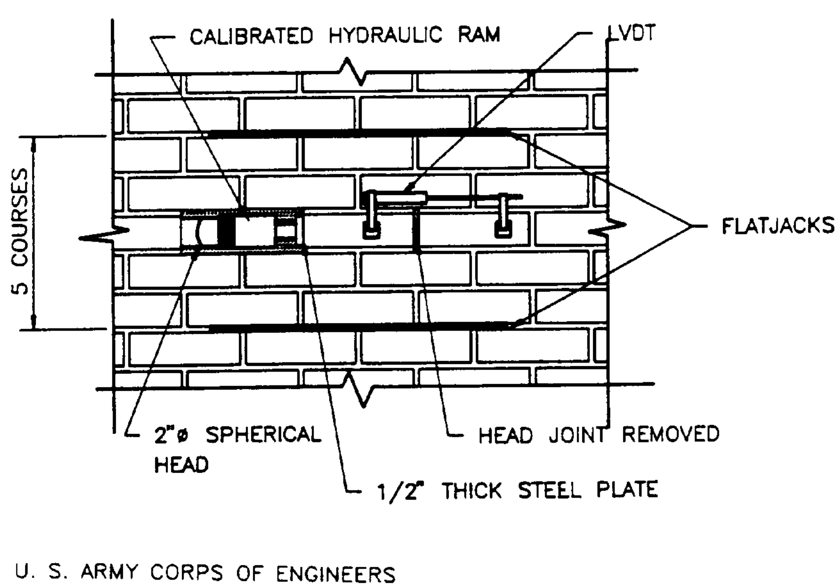


*Figure 10–4. Setup for modified in-place shear test.*

have been shown to influence ultrasonic measurements in concrete; including, among others; aggregate type and size, moisture content, and the presence of reinforcement. Generally, those factors which can affect compressive strength may also affect ultrasonic pulse velocity, though not necessarily in direct proportion. Strength predictions can only be justified if a calibration of pulse velocity with masonry strength is made for the specific structure under consideration, and then only if the conditions of testing can be carefully controlled. The empirical relationship between ultrasonic pulse velocity and masonry compressive strength must, in effect, be established for every structure evaluated. Because of this limitation, the pulse velocity method is generally used only to measure material uniformity over a large area of a structure.

(2) *Equipment.* Equipment needed for ultrasonic investigations consists of two transducers (transmitter and receiver), transducer leads, and a power unit with digital transit time display. A transient wave recorder can also be useful to provide hard copy records of the signals. These records can then be fed into a portable computer for more sophisticated analysis of the signals.

(3) *Experimental procedure.* Two types of tests are typically conducted: (a) Direct (or through-wall) tests in which the sending and receiving transducers are placed in line with one another on opposite sides of the test wall; and (b) Indirect tests in which the transducers are located on the same face of the wall in a vertical or horizontal line. These test configurations are illustrated in figure 10-5. The simplest way to utilize ultrasonic wave transmission data is to simply record the arrival time and the pathlength and calculate an average velocity for the pulse. The determination of arrival time is simplified by the use of a digital readout on the device. If the digital readout is not used, it is possible to analyze the wave trace to determine the arrival time. Data may then be displayed in any of several forms including x-y plots of pulse path length versus pulse travel time, contour maps of arrival time, or contour maps of pulse transmission quality.

(4) *Indirect tests.* Indirect tests are useful for determining the average velocity through a single outer wythe of masonry, and for locating flaws in the outer wythes. A distinct flaw, such as a delaminated bed joint, will cause a reduction in the pulse velocity in the vicinity of the flaw. Hence, an area of lesser quality material can be expected to have a slower pulse velocity. Clay brick masonry, if built with weak mortar and low strength units, may attenuate the high frequency stress wave to the

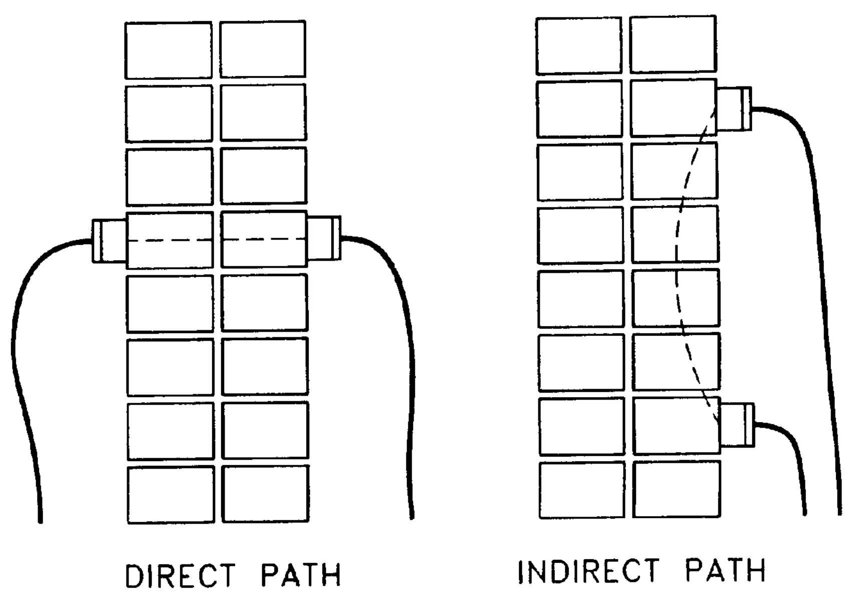


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*Figure 10–5. Typical ultrasonic test configurations.*

point where the distance between transducers is very small, such as one foot, and reduce the usefulness of the method.

(5) *Direct (through-wall)* tests. Figure 10-6 shows a three dimensional surface representing the variation in ultrasonic pulse arrival time over the area of a masonry wall. The vertical dimension is the arrival time, so humps on the plot indicate areas of relatively long arrival time and thus areas of potential voids. The test wall in figure 10-6 was constructed with known flaws in the masonry. While the exterior wythes of this wall were constructed of uniform quality, the interior wythe had varying materials and workmanship. In general, the highest quality materials were located in the lower courses of the interior wythe, and the quality deteriorated with increasing height in the wall. The most significant flaw was an air space in the upper right portion of the wall. The location of the air space in the interior wythe is clearly outlined in both the contour and surface plots. The less dramatic changes in material quality over the height of the wall are apparent as small changes in arrival time between the top and bottom halves of the wall.

(6) *Application.* While the use of ultrasonic techniques has been successful for the evaluation of concrete, the method is less well suited to heterogeneous materials such as masonry. The attenuation of a stress wave is related to its wavelength and the size of the largest flaws in its path. As the relatively short wavelength of the ultrasonic pulse passes through each mortar joint, the pulse suffers considerable energy loss, resulting in extremely rapid signal attenuation. This attenuation inhibits the use of ultrasonics over all but the shortest pathlengths. Because of the limitations of the ultrasonic method applied to masonry, lower frequency sonic testing (1 to 5 kHz) (a.k.a. "mechanical pulse testing") should be used in NDE techniques for masonry structures.

*e. Mechanical pulse.* This method, called "Mechanical Pulse Velocity" testing, involves input of a stress wave into a masonry wall by means of a hammer blow, and recording of the subsequent vibrations with an accelerometer. This technique, due to its low frequency, high-amplitude, long-wavelength signal, is better suited to the evaluation of masonry than the ultrasonic technique. As with ultrasonic testing, the quantity of interest has traditionally been the arrival time of the pulse,

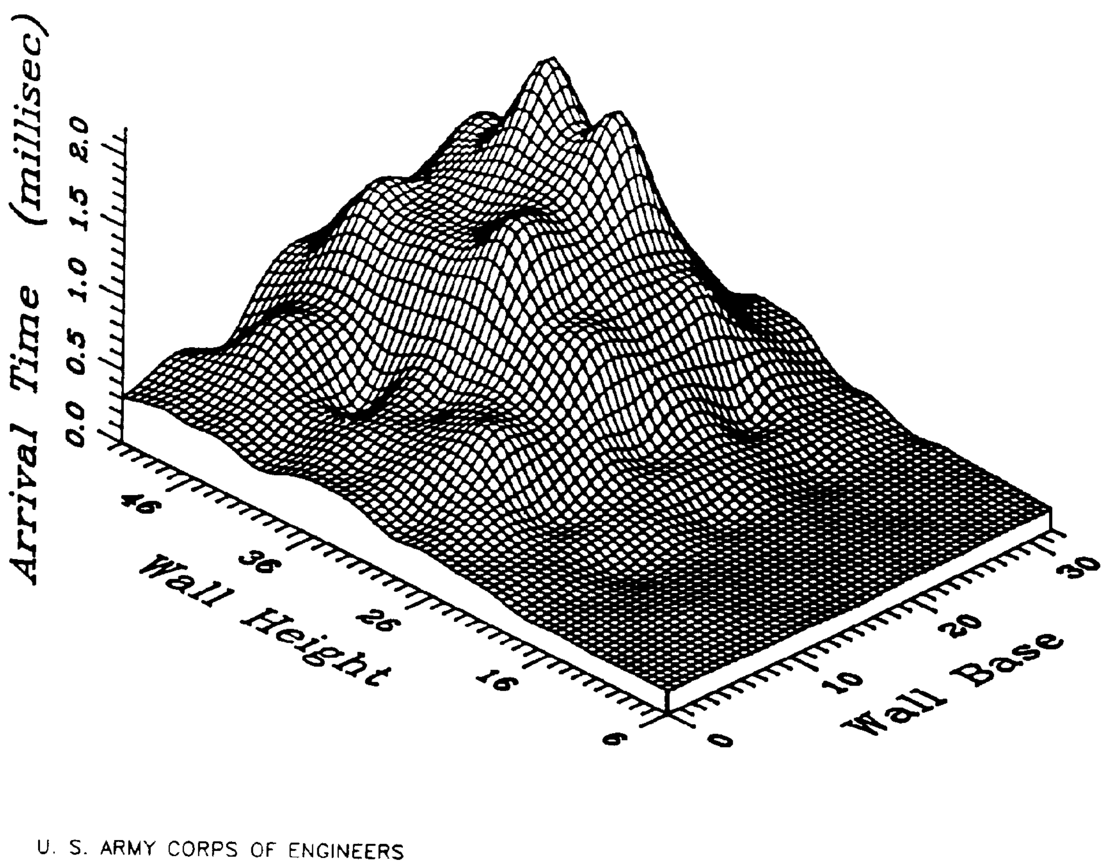


*Figure 10–6. Three-dimensional surface representing through-wall ultrasonic pulse arrival time.*

which, in conjunction with the pathlength, gives a simple indication of pulse velocity. The pulse velocity can, to various degrees of accuracy, be correlated with material properties. In addition, sonic techniques can be used to locate material flaws, however, the long wave length that makes a sonic pulse appropriate for testing long expanses of brick work also increases the minimum size flaw that can be detected.

(1) *Equipment.* The basic equipment used for conducting mechanical pulse tests includes a 3 pound modally tuned hammer and an accelerometer. Unlike the ultrasonic test equipment, there is no digital readout of travel time with this equipment, so the signal must be recorded or displayed on an external device. A digital transient recorder can be used to record both the hammer input signal and the accelerometer output signals. The signals can then be saved on floppy disks through a portable computer. The testing apparatus is shown in figure 10-7. Alternatively, an oscilloscope may be used to measure travel time.

(2) *Use.* Test results for mechanical pulse tests are much the same as those for ultrasonic pulse velocity as described previously. The simplest way to utilize mechanical wave transmission data is to simply record the arrival time and the pathlength and calculate an average velocity for the pulse. The recorded data should then be plotted in some understandable format. Two dimensional contours or three dimensional surface plots are recommended for direct tests, and x-y plots are recommended for indirect tests. Figure 10-8 plots the pulse path length against the arrival time for an indirect mechanical pulse test. The presence of a distinct flaw causes a noticeable break in the velocity line.

(3) *Application.* The mechanical pulse technique is best suited to the task of locating flaws and discontinuities such as missing mortar joints and large cracks and establishing relative quality of masonry from one location to another. Indirect tests are useful for determining the average velocity through a single outer wythe of masonry, and for locating flaws in the outer wythes. Direct tests are able to locate flaws and voids in interior wythes and collar joints. The mechanical pulse technique is superior to the ultrasonic system for flaw detection

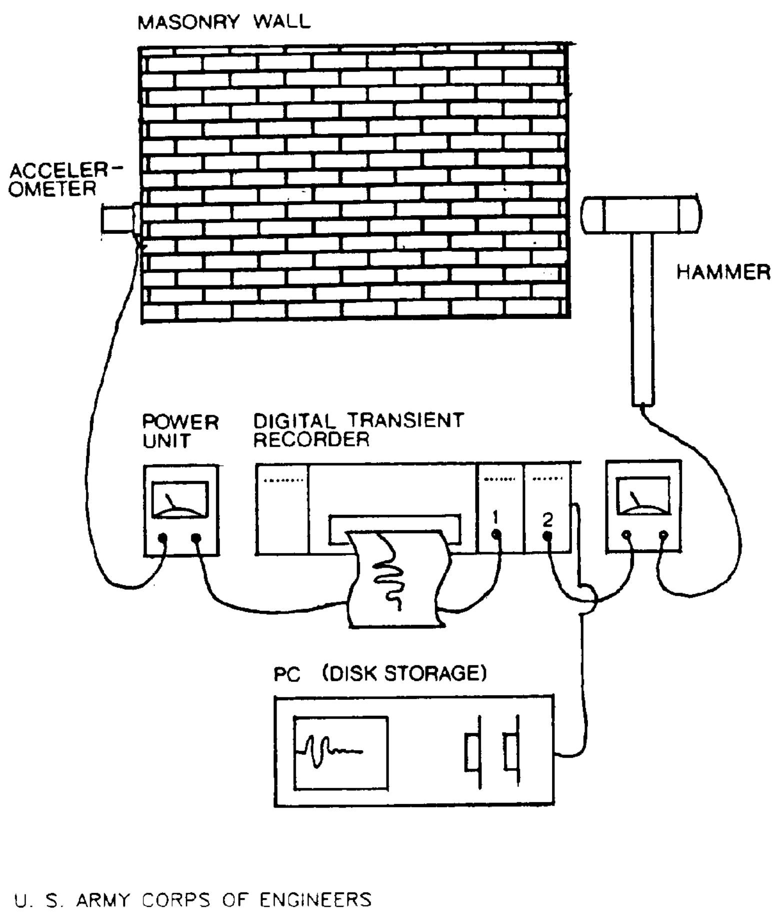


*Figure 10–7. Mechanical pulse testing apparatus.*

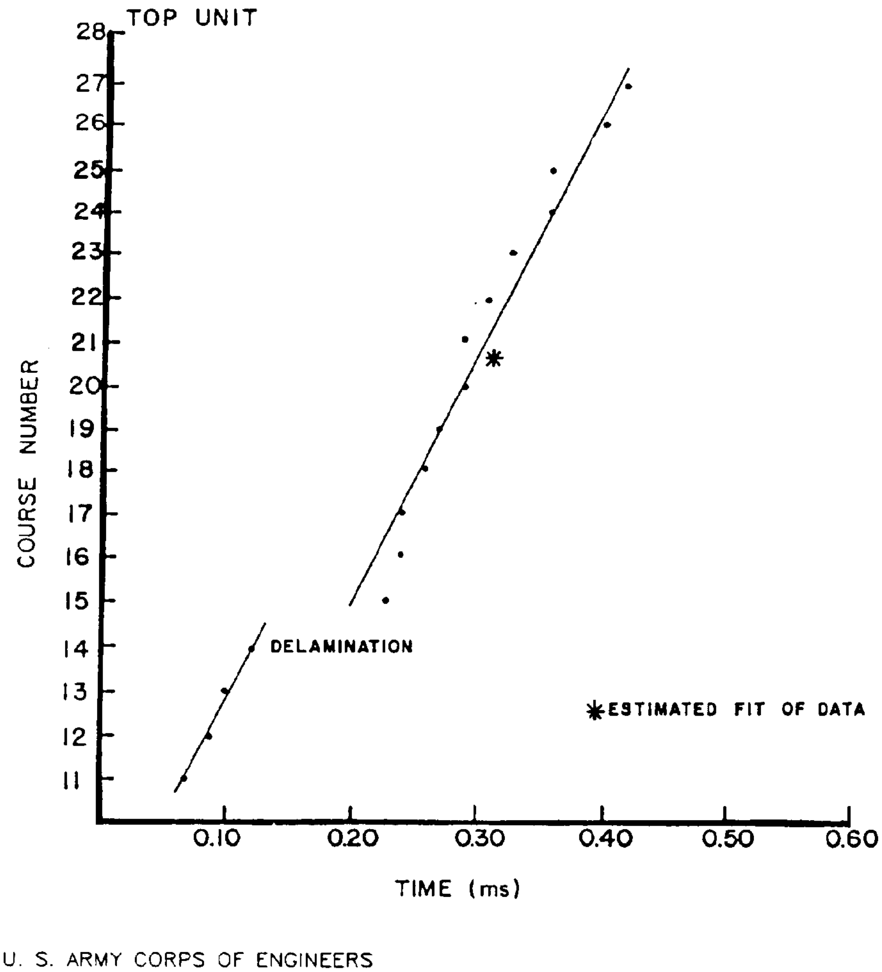


*Figure 10–8. Pulse path length vs. arrival time.*

and condition assessment in masonry structures particularly in the case of older unreinforced brick masonry. The primary difference between the two techniques is the amplitude and wavelength of the input pulse, both of which are larger for the mechanical pulse tests. The high energy and long wavelength of its input wave are not as rapidly attenuated by the boundaries between units and mortar that are intrinsic parts of masonry construction. Because of this, the mechanical pulse will travel farther through most masonry materials than the ultrasonic pulse. In addition, the mechanical pulse technique is sensitive enough to detect larger flaws that are of interest in a structural evaluation. Thus, for masonry, the mechanical pulse system is generally preferable to the ultrasonic system. Because of potential difficulties in the interpretation of data, mechanical pulse tests are best conducted in conjunction with flatjack tests, so that the influence of varying vertical stresses and varying material deformability on the mechanical pulse measurements can be assessed. The single case where the ultrasonic pulse is preferable to the mechanical pulse is when the desired path length is very short and the quality of the masonry is generally good, as in through-wall transmission tests in grouted concrete masonry. In this case, the mechanical pulse system is unable to detect the typically small flaws or delaminations.

*f. Location of reinforcement and ties.* The use of magnetic and resistance methods allows quick inspection of masonry construction for the presence of steel reinforcement or ties. These techniques may be useful for quality control as a means of verifying compliance with construction plans, and provide reasonable results when expected reinforcing bar sizes and locations are known. More difficult is the case of retrofit or renovation projects, when it is necessary to not only locate the reinforcement, but also estimate the size and depth to the bar. Commercially available equipment typically utilizes an electromagnetic field generated around a hand-held probe to indicate the presence of steel in the masonry. A voltage change occurs when the field is interrupted by a ferrous material, such as a steel reinforcing bar. The magnitude of the voltage change is proportional to the amount of steel and the distance from the steel to the probe. The application of the test is done by cover meters used to locate the presence of vertical and horizontal reinforcement, joint reinforcement, and metal ties or connectors. The equipment is compact and portable, allowing the operator to quickly map reinforcing locations and patterns. Cover meters will, however, locate all steel present, not just the reinforcing bars. Some care needs to be taken not to identify metal ties, nails, electrical conduit, etc., as reinforcing steel. While cover meters are able to accurately determine the presence of reinforcing steel, some interpretation is needed if either the size of the reinforcement or the depth within the masonry is to be estimated. A weak signal can indicate either a small bar close to the surface, or a larger bar located farther from the probe. Hence, it may be necessary to expose the reinforcement at trial locations to verify assumptions regarding size and location.

*g. Nuclear methods.* Although not related directly to structural properties of materials, the Neutron-Gamma technique shows great promise for certain aspects of masonry evaluation. The technique measures element concentrations in masonry walls, and thus gives information about moisture content, presence of salts, and elemental composition of the masonry materials. The technique has been shown to be complementary to structural evaluation techniques by aiding the interpretation of results from tests such as the mechanical pulse technique.

**10-6. Advantages and disadvantages of all NDE tests.**

*a. Schmidt Hammer test.*

(1) *Advantages.*

*(a)* Simple to use. No special experience is needed to conduct the test.

*(b)* Establishes uniformity of properties.

*(c)* Equipment is inexpensive and is readily available. It is relatively simple and inexpensive to conduct a large number of tests. The equipment for the test is readily available.

(2) *Disadvantages.*

*(a)* Evaluates only the local point and layer (wythe) of masonry to which it is applied.

*(b)* No direct relationship to strength or deformation properties.

*(c)* Unreliable for the detection of flaws.

*(d)* Evaluates only the layer (wythe) of masonry to which it is applied, and is unreliable for detection of flaws or for investigation of inaccessible masonry wythes.

*b. Single Flatjack in-situ stress test.*

(1) *Advantages.*

*(a)* Can establish the state of compressive stress, in-situ, with reasonable accuracy.

*(b)* Inexpensive materials and equipment.

*(c)* Uncomplicated to use.

*(d)* ASTM standards currently being developed.

(2) *Disadvantages.*

*(a)* Somewhat time-consuming to prepare the test, when compared to other methods.

*(b)* Requires removal of mortar from masonry bed joint with a saw or drill.

*(c)* Requires repair of the mortar joint after testing.

*c. Double Flatjack in-situ deformability test.*

(1) *Advantages.*

*(a)* Can establish deformation properties, in-situ, with reasonable accuracy.

*(b)* Inexpensive materials and equipment.

*(c)* Uncomplicated to use.

*(d)* ASTM standards currently being developed.

(2) *Disadvantages.*

*(a)* Somewhat time consuming to prepare the test, when compared to other methods.

*(b)* Requires removal of mortar from masonry bed joint with a saw or drill.

*(c)* Requires repair of the mortar joint after testing.

*d. In-place shear test.*

(1) *Advantages.*

*(a)* Can establish joint shear strength in-situ.

*(b)* Equipment is inexpensive and readily available.

*(c)* Uncomplicated to use.

(2) *Disadvantages.*

*(a)* Somewhat time consuming to prepare.

*(b)* Requires removal of a masonry unit and a head joint.

*(c)* Restricted to masonry with low cement content mortar.

*(d)* Requires unit and mortar replacement after the test.

*(e)* State of compressive stress on the test unit must be estimated.

*(f)* Contribution of the collar joint is unknown.

*e. Two Flatjack modified in-place shear test.*

(1) *Advantages.*

*(a)* Can establish the joint shear strength in-situ with reasonable accuracy.

*(b)* Permits control of compressive stress on test unit.

*(c)* Determines the Coulomb failure surface for the material.

(2) *Disadvantages.*

*(a)* Somewhat time consuming to prepare.

*(b)* Requires removal of two masonry units.

*(c)* Restricted to masonry with low cement-content mortar.

*(d)* Requires unit replacement after the test.

*(e)* Contribution of collar joint is unknown.

*(f)* Requires removal and replacement of two mortar joints.

*(g)* Large amount of equipment is required.

*f.* *Ultrasonic pulse velocity.*

(1) *Advantages.*

*(a)* Simple to use.

*(b)* Establishes uniformity of properties.

*(c)* Can detect flaws, cracks, or voids.

*d)* Possible to record trace of stress wave for analysis.

*(e)* Equipment readily available and only moderately expensive.

*(f)* Equipment package is self contained and portable.

(2) *Disadvantages.*

*(a)* Requires access to both sides of a wall for direct measurements.

*(b)* Attenuation of signal in older or soft masonry restricts distance between transducers for indirect and semi-direct use.

*(c)* Coupling material needed between masonry and transducers, which may alter the appearance of the masonry.

*(d)* Grinding may be required to prepare a rough surface.

*(e)* No direct correlation with material properties.

*g.* *Mechanical pulse velocity.*

(1) *Advantages.*

*(a)* Reasonably simple to use.

*(b)* Establishes uniformity of properties.

*(c)* Can detect flaws, cracks, and voids.

*(d)* Possible to record trace of stress wave for later analysis.

*(e)* Equipment is readily available and only moderately expensive.

*(f)* Capable of testing over long distances in any type of masonry.

*(g)* Does not damage the masonry.

(2) *Disadvantages.*

*(a)* Several pieces of equipment are involved, not easily portable.

*(b)* Requires a separate instrument to record the wave arrival time.

*(c)* No direct correlation between results and material properties.

*(d)* Analysis of the wave trace can be complicated.

*h.* *Magnetic methods.*

(1) *Advantages.*

*(a)* Equipment is portable and inexpensive.

*(b)* Large areas of masonry can be quickly evaluated.

*(c)* Accurately maps location and orientation or reinforcing steel in masonry.

*(d)* Can be used to locate metal ties and connectors.

(2) *Disadvantages.*

*(a)* Readings can be ambiguous, requiring operator interpretation or destructive tests to verify conclusions.

*(b)* Misidentification of metal conduit, etc., as reinforcing steel is possible.

*(c)* Accuracy in determination of bar size and depth is questionable.